Millimetre Waves: Modelling and Simulation to Engineer for Coverage

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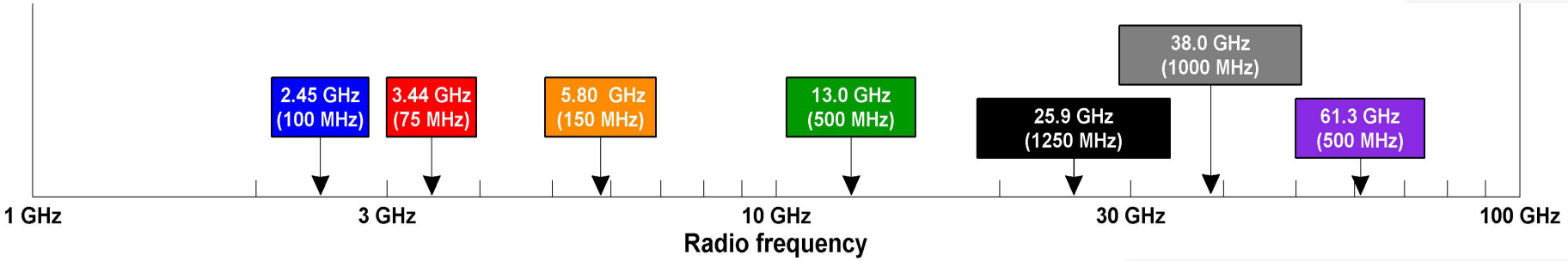
Agenda

- Introduction and Scope
- Propagation
- Modelling and Simulation
- Engineer for Coverage
- Experimentation
- Summary

Scope of 5G work in Millimetre Waves at CRC

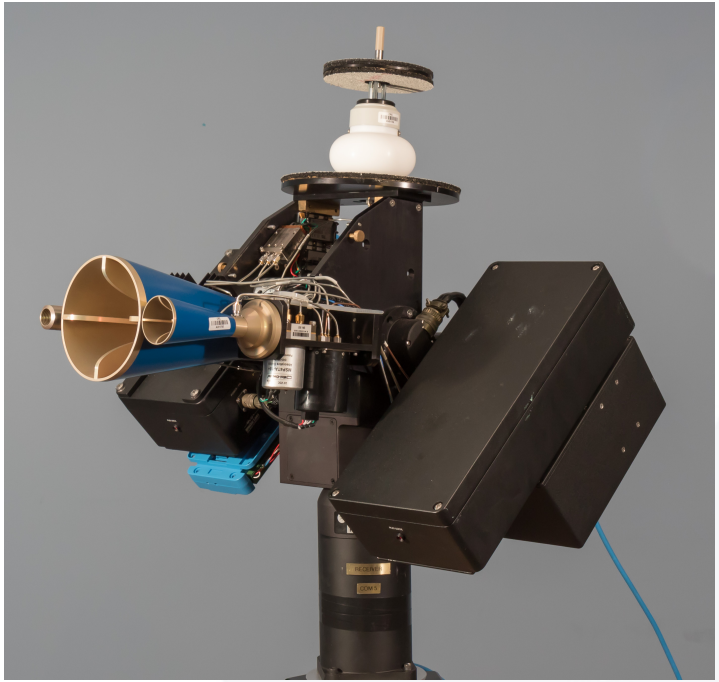
- Communications Research Centre (CRC) Canada is the spectrum regulator's R&D organization
- Take systems approach to engineer the urban environment for 28 GHz 5G coverage
- Use propagation measurement, modelling and radio experimentation to validate
- Provide spectrum regulator with technical information that may impact policies and regulation

Propagation



Measurement System

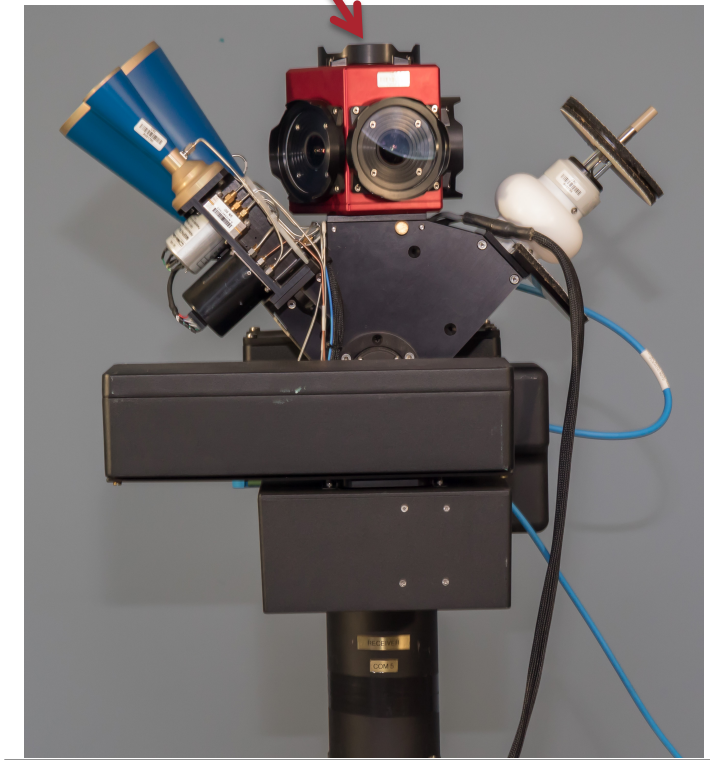
- Vector network analyzer (VNA) based system for double-directional channel characterization
- Wideband measurements in 7 frequency bands in the 2–60 GHz range
- Vertical and horizontal polarization
- Directional scanning via mechanical antenna steering
- 50m cable between Tx and Rx limits range

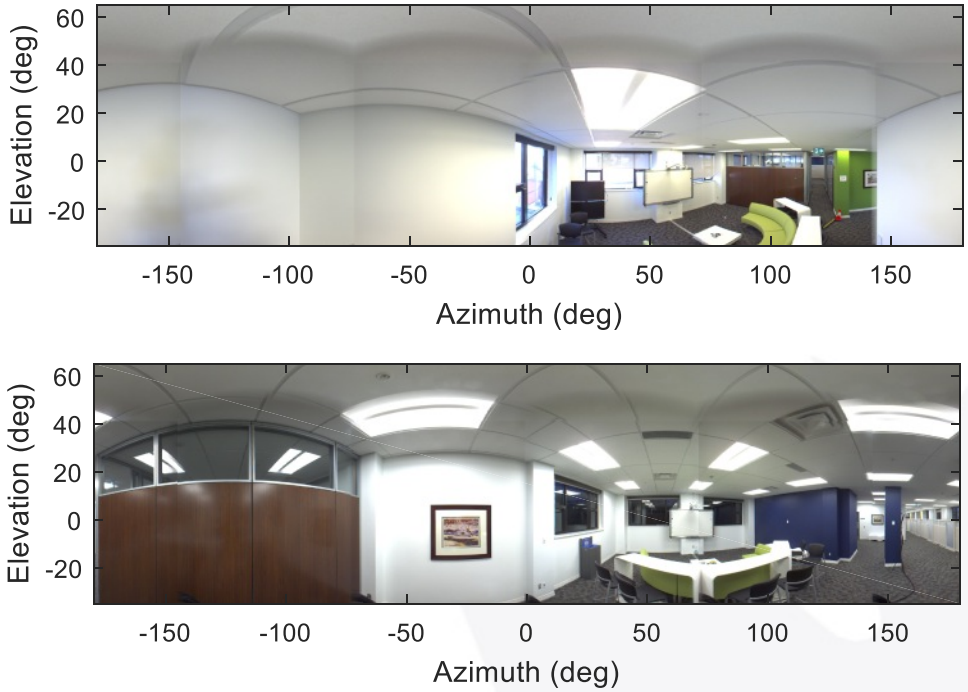


Tx and Rx equipment- mounted with antennas, pan/tilt units

Visualization Subsystem

Panoramic camera

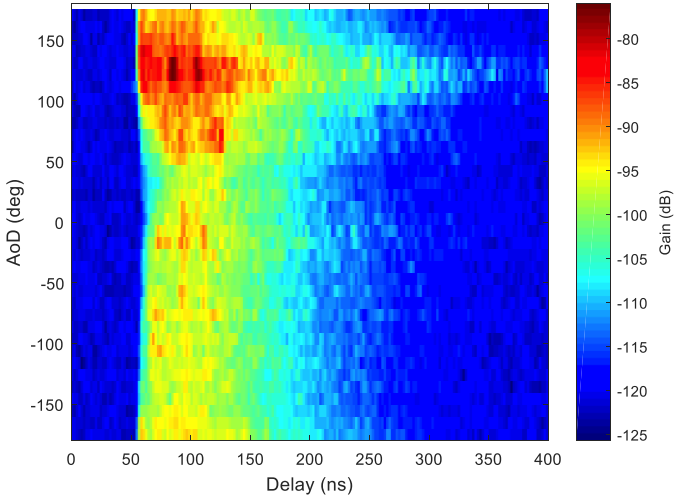


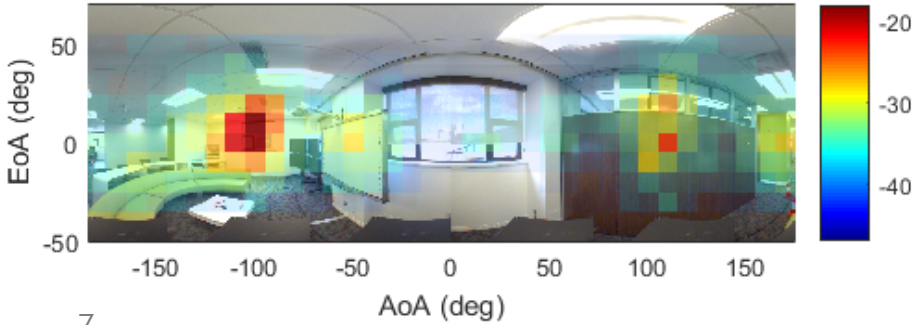


Calibrated panoramic images

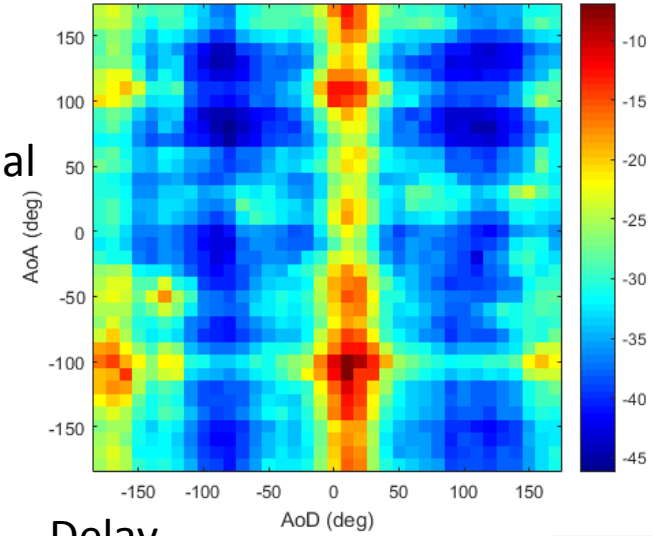
Measurement and Visualization

AoD versus delay



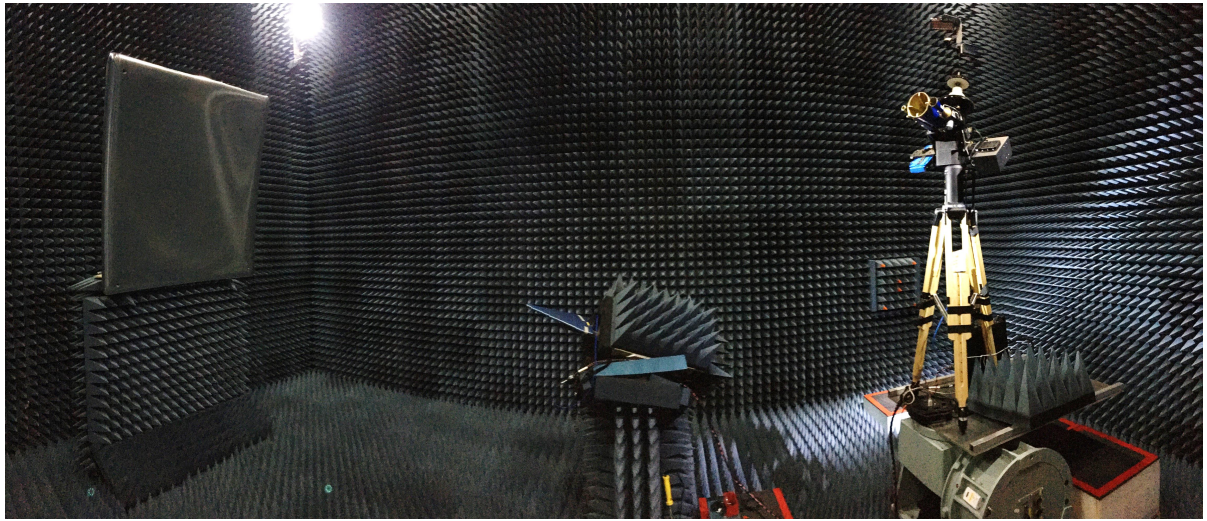


Double-directional

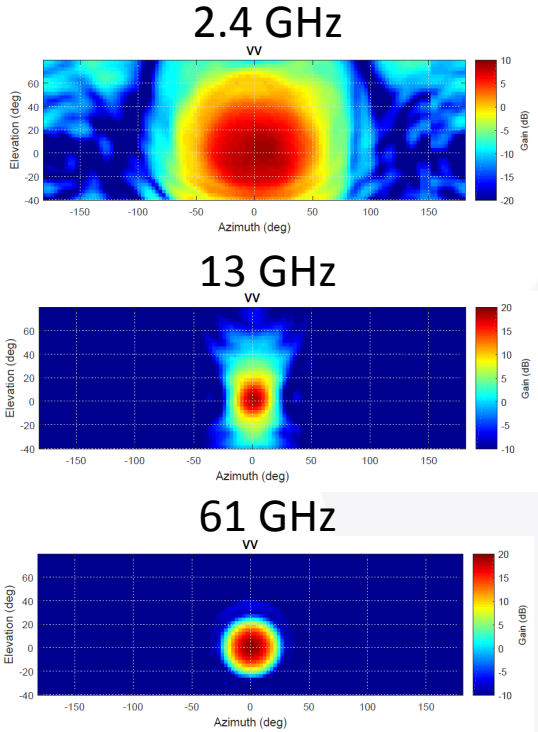


1. Delay
2. Azimuth-of-departure (AoD)
3. Elevation-of-departure (EoD)
4. Azimuth-of-arrival (AoA)
5. Elevation-of-arrival (EoA)

Antenna Characterization

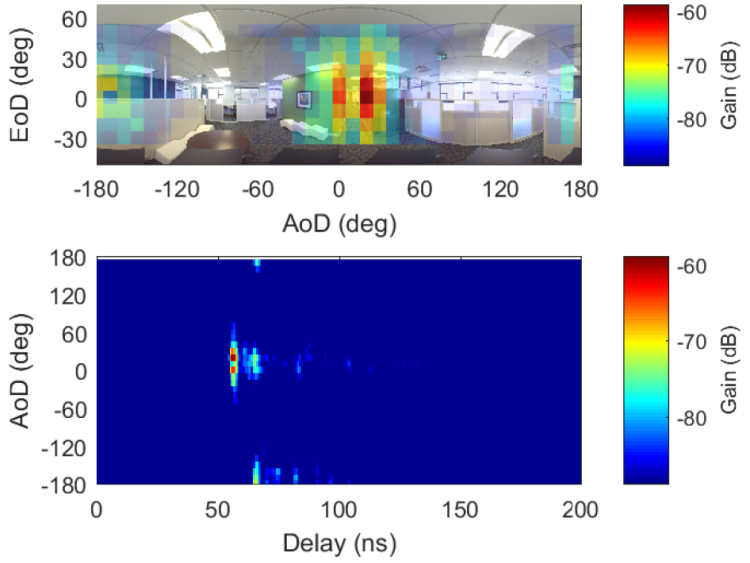


Antenna characterization in CRC compact range

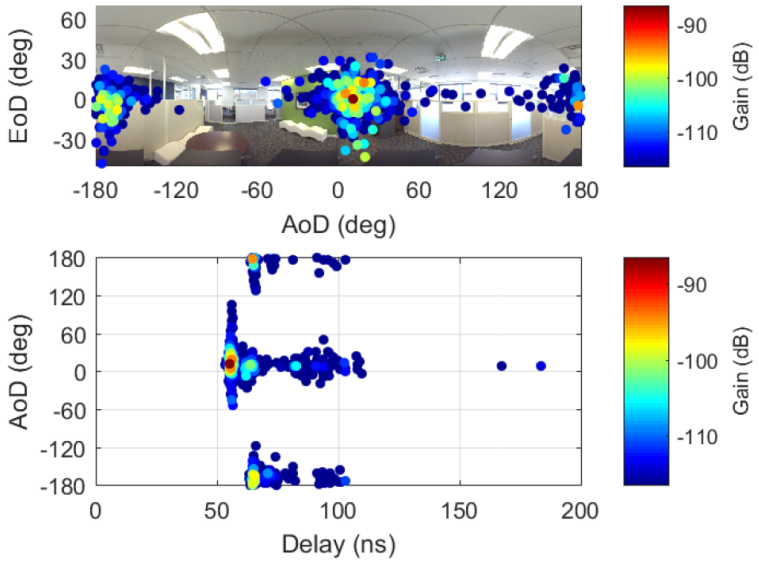


Data Processing (CLEAN Algorithm*)

- Extract discrete multipath parameters (delay, DoD, DoA)
- Iterative technique to de-embed system (antenna characteristics)



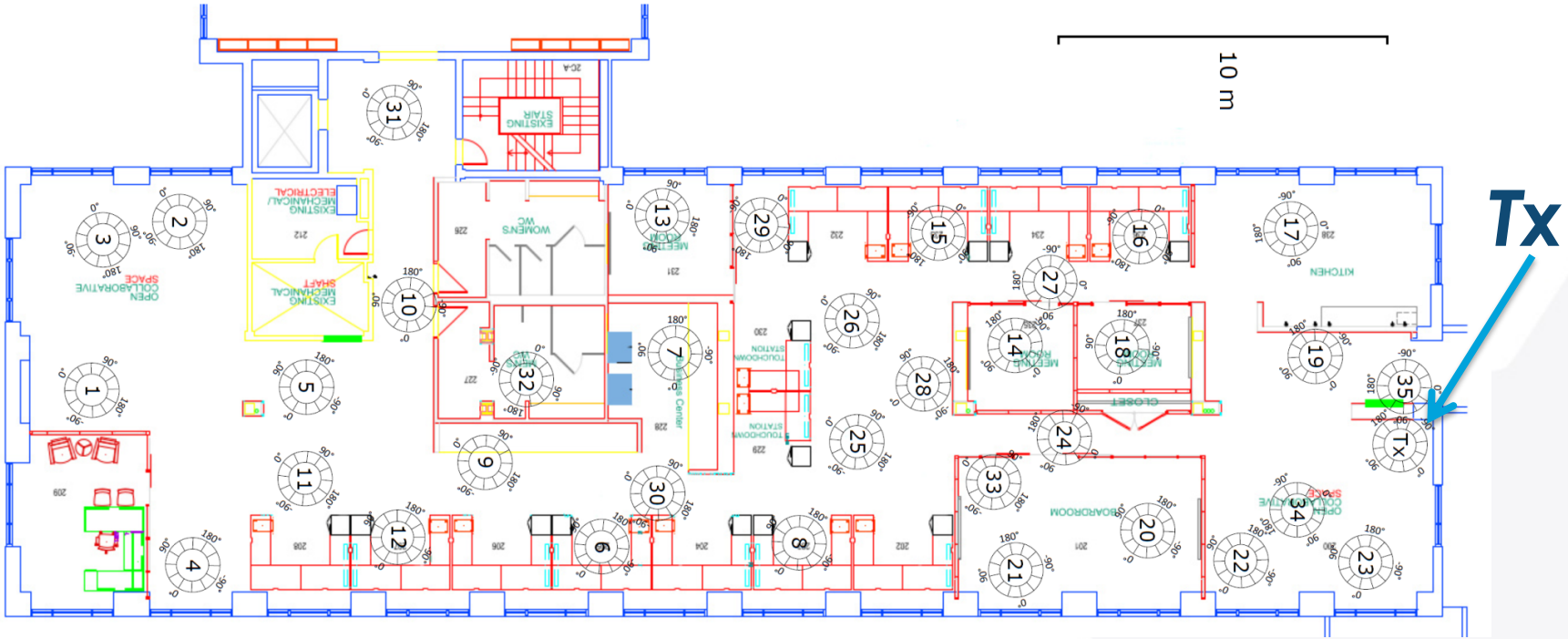
Raw data



Processed data

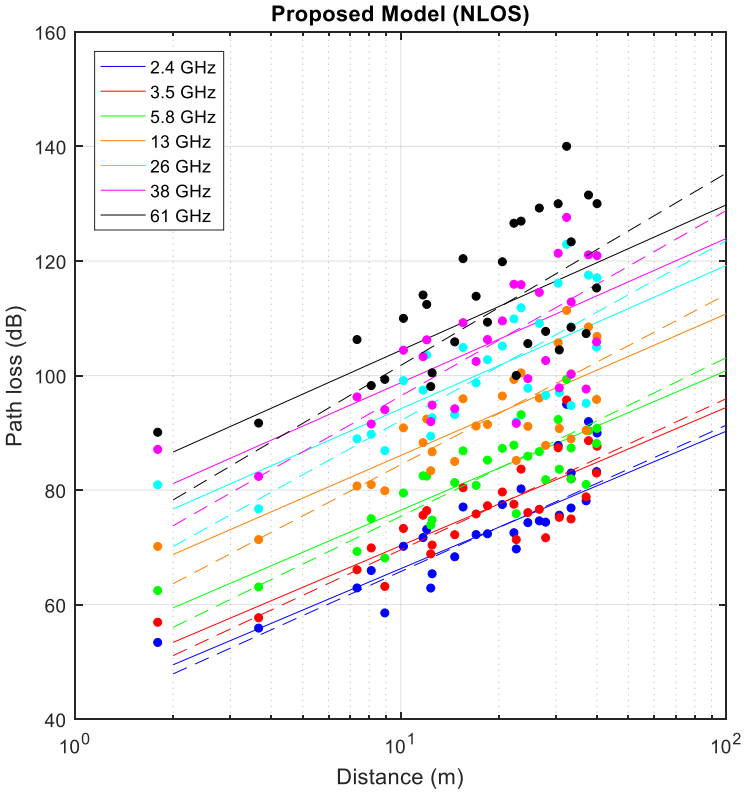
*J.A. Högborn, "Aperture synthesis with a non-regular distribution of interferometer baselines", *Astron. And Astrophysics, Suppl. Ser.* Vol. 15, 1974.

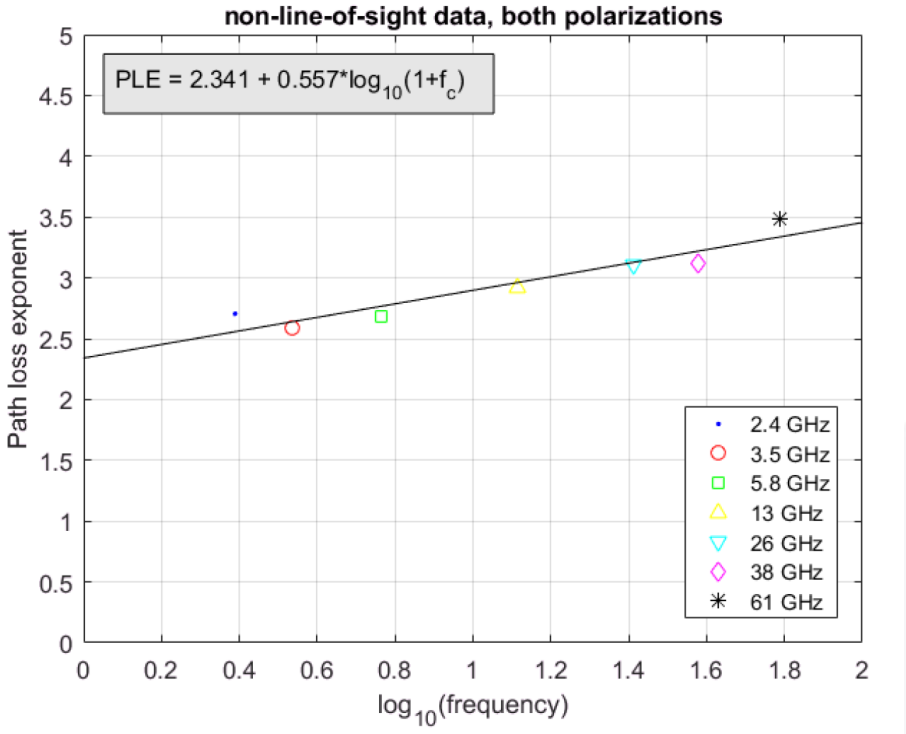
Indoor Measurements at CRC



Modern open office with cubicles, meeting rooms and a few offices with glass walls.

Indoor Measurements- Path Loss

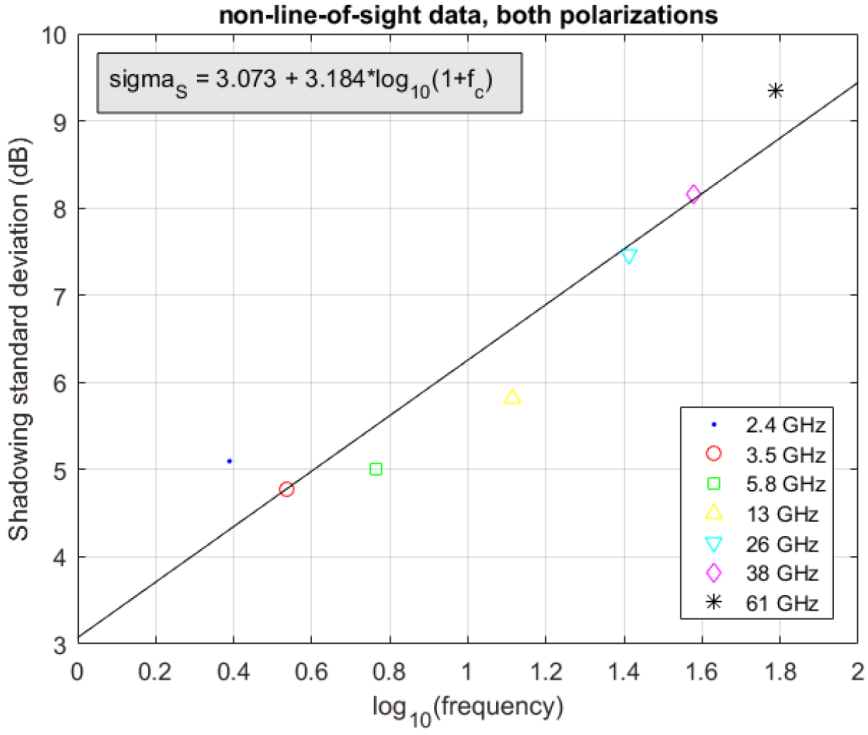




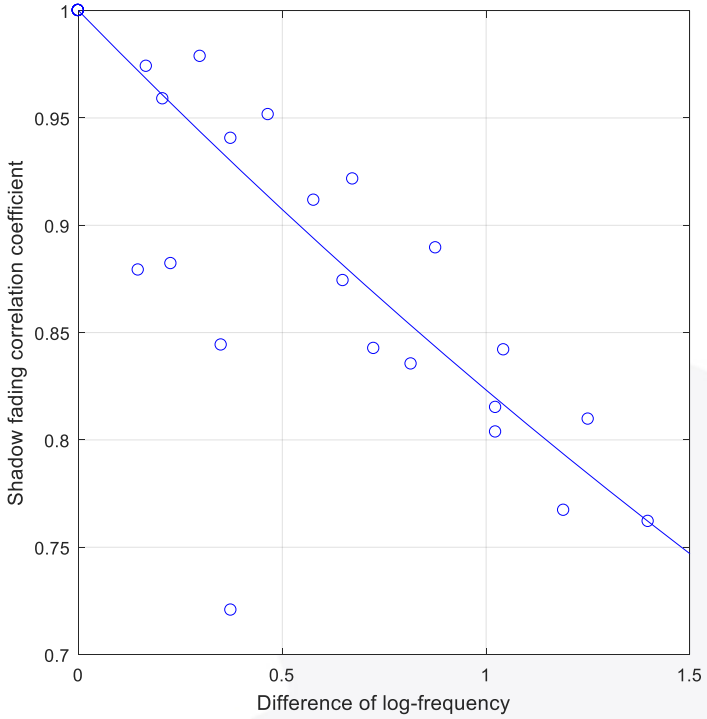
Path loss

Path loss exponent

Shadow Fading- Variability Around Model



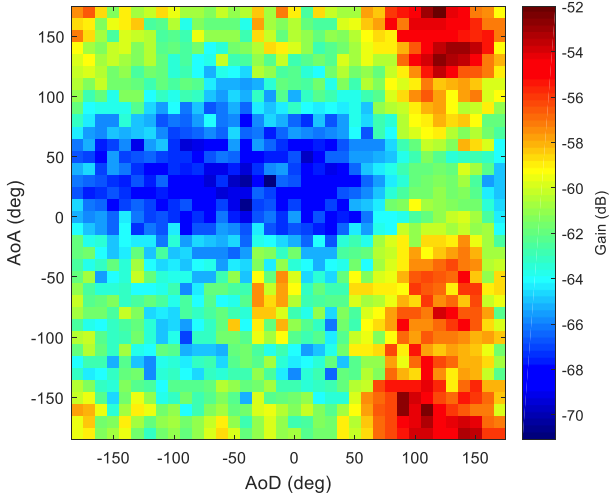
Shadow fading



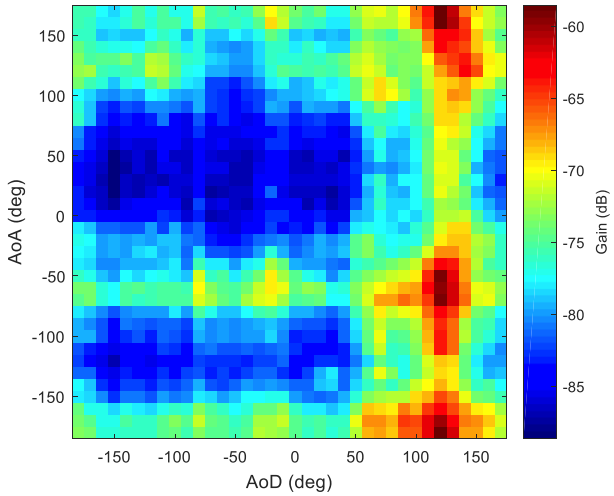
Shadow fading correlation

Study Impact of Frequency on Channel Structure Propagation Parameters

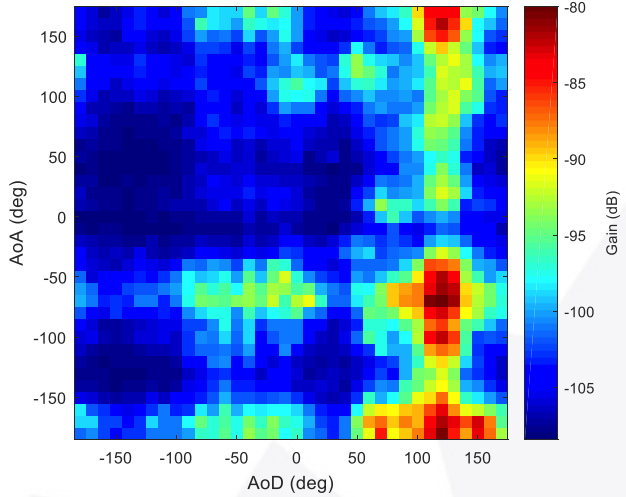
2.4 GHz



13 GHz

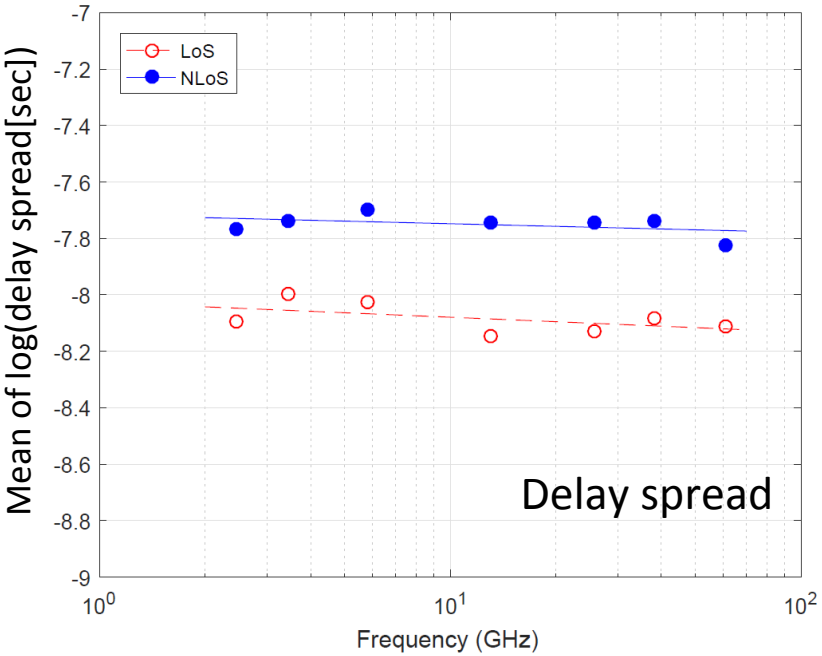


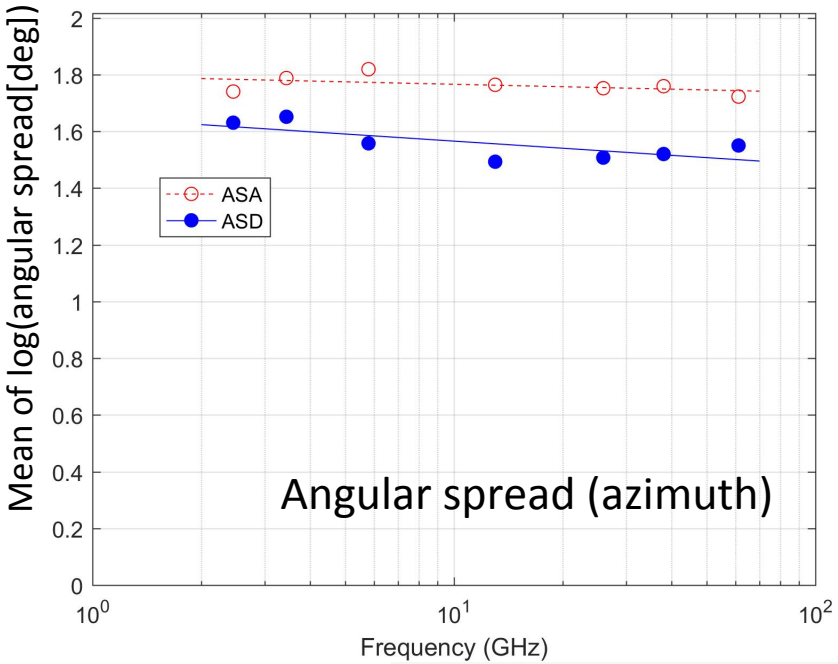
61 GHz



- Multipath parameters very similar across frequency bands
- Channel sounder characteristics vary with frequency

Channel structure Demonstrates Invariance to Frequency (Indoor measurements)

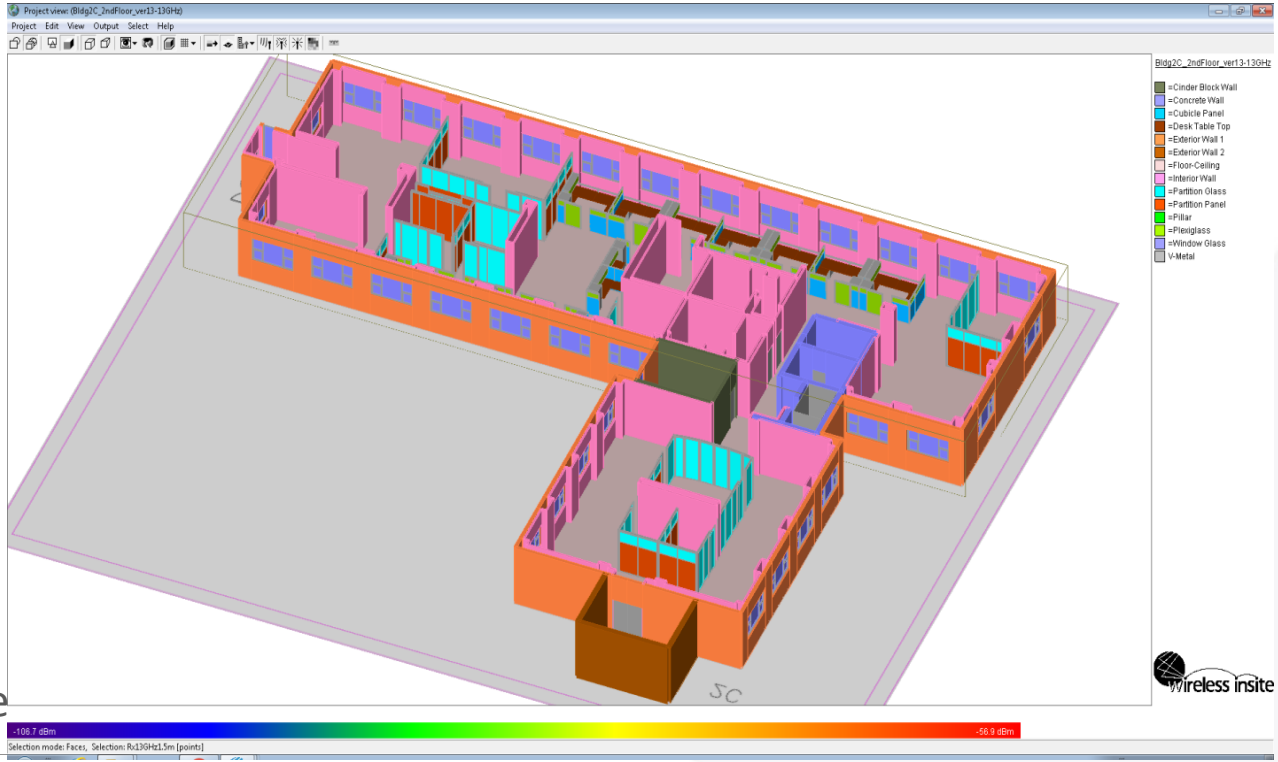




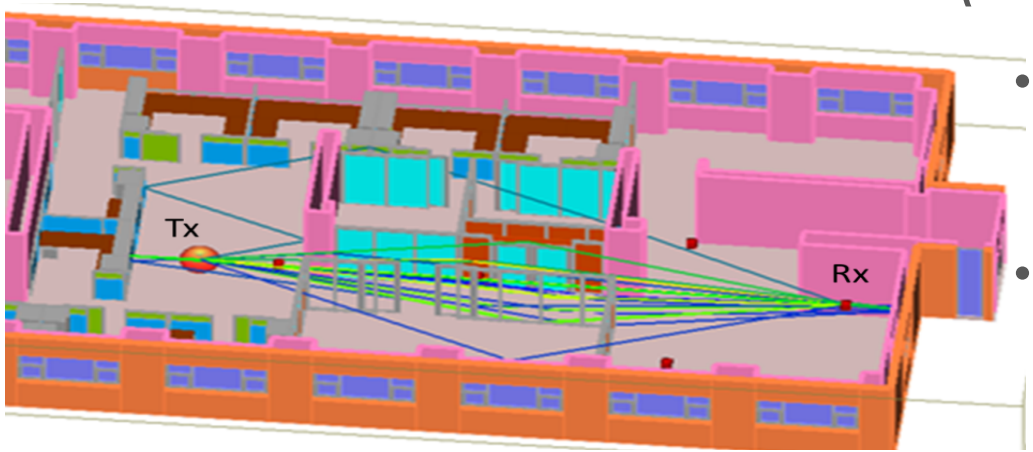
Impact of measurement system removed during processing

Modelling and Simulation

- Legacy Building at CRC with modern interior
- Model created from blueprints
- Electrical properties of building materials used
- Wireless Insite sensitive to model approach (eg. use layers not volumes)
- Simulations at many frequencies easy to generate once model stable

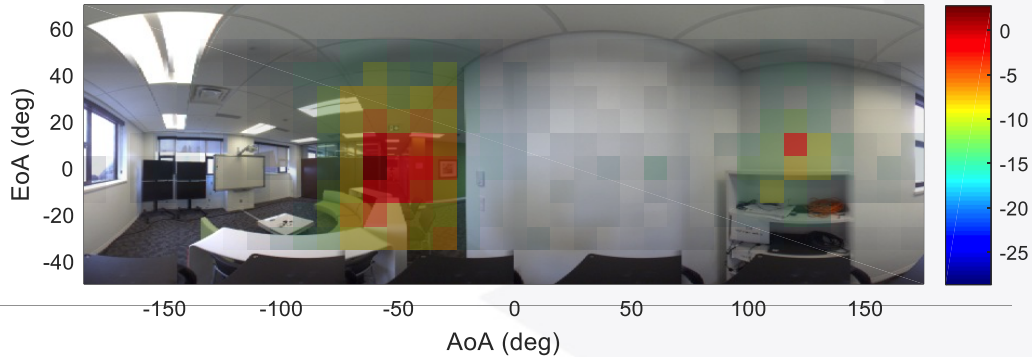


Validation of Simulation with Measurement: LOS Scenario at 26 GHz (1 of 2)



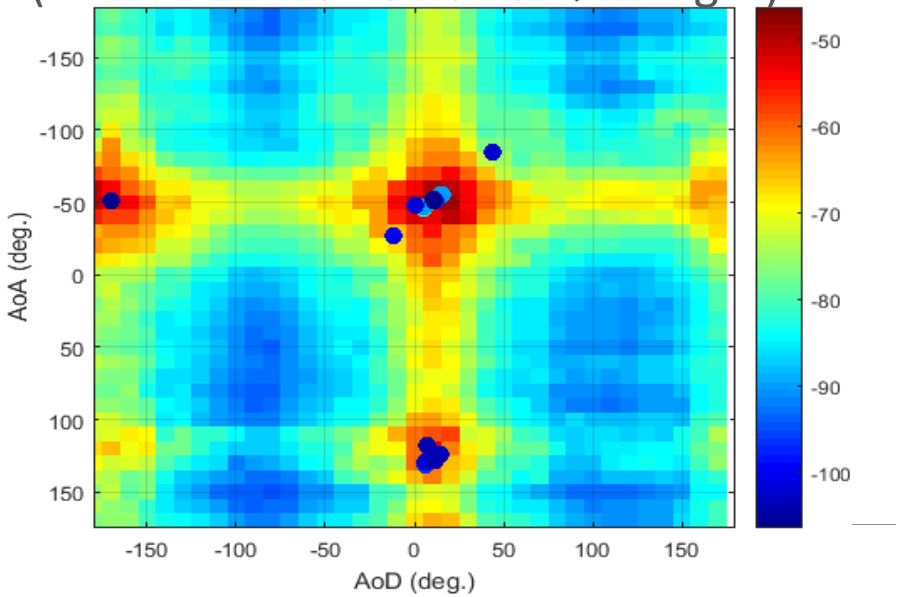
- From ray tracing result we obtain spatial and delay properties of channel
- Propagation measurements for same locations show the strong main path and some multipath

- Image shows arrival power at Rx at -50 degrees, and multipath at +130 degrees (180 degree difference)

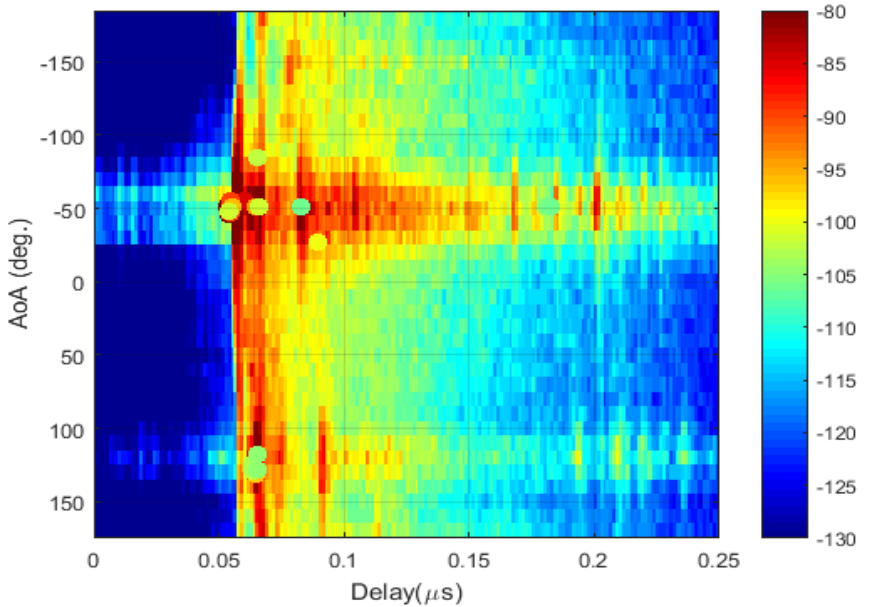


Validation of Simulation with Measurement: LOS Scenario at 26 GHz (2 of 2)

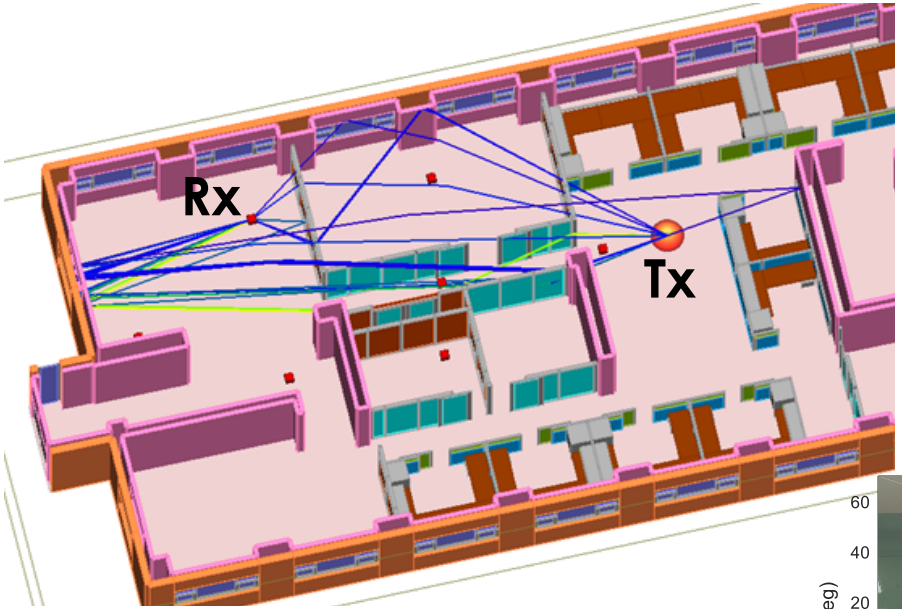
- Spatial measured results (heat map) with corresponding simulation results
- Circles indicate presence of signal (colour does not indicate strength)



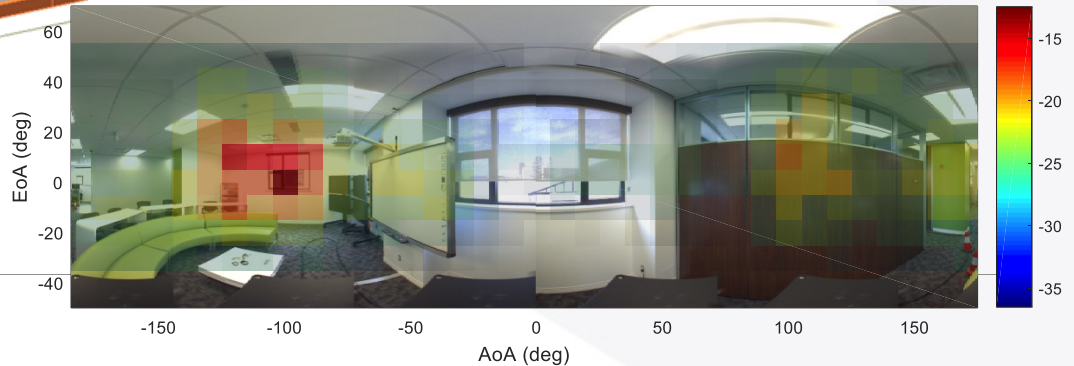
- Delay domain of simulation and measured match for strong elements



Validation of Simulation with Measurement: NLOS Scenario at 26 GHz (1 of 2)

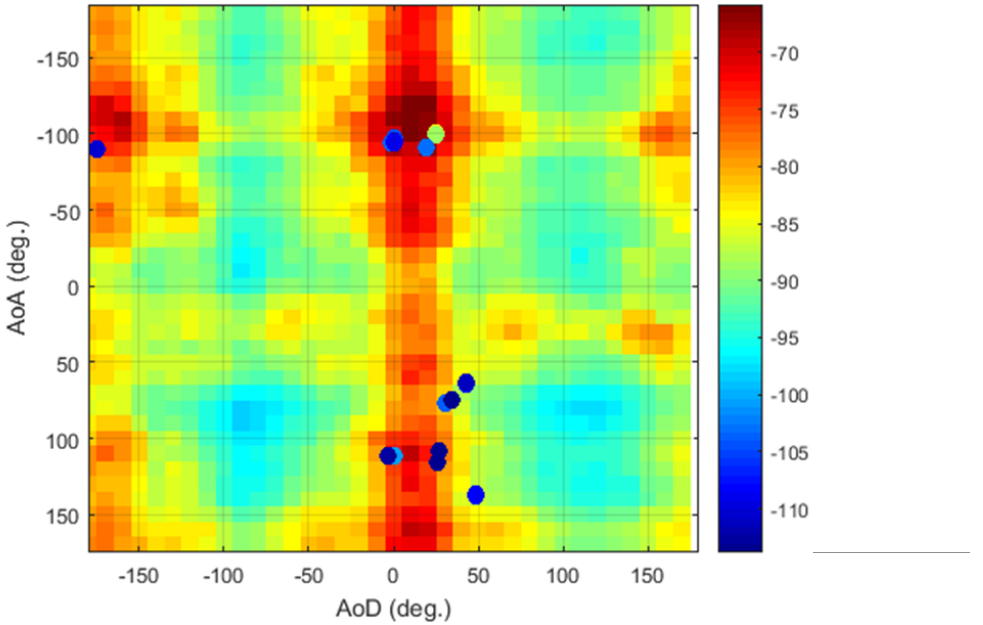


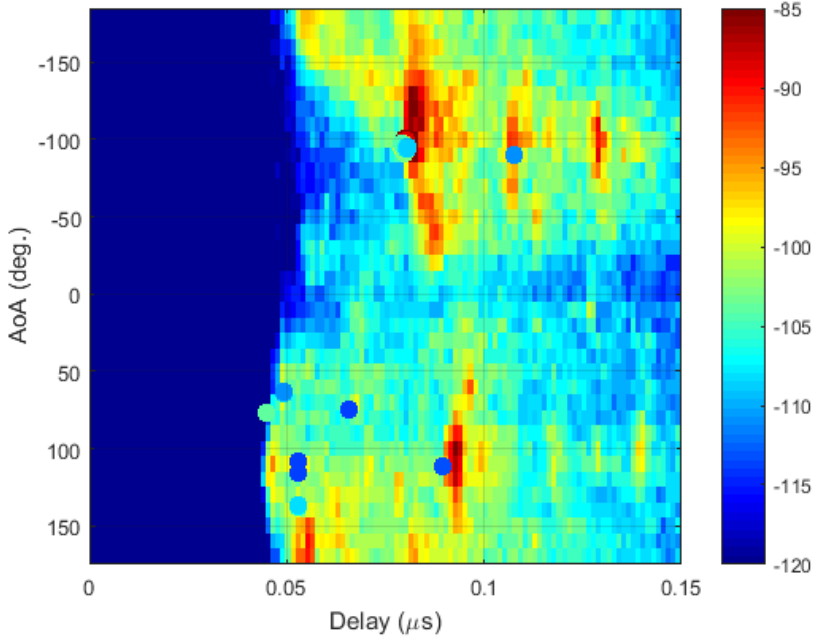
- Propagation measurements for same locations show several viable paths between Tx and Rx
- Image shows signals received from wider set of angles



Validation of Simulation with Measurement: NLOS Scenario at 26 GHz (2 of 2)

- Spatial and delay measured results with strong elements match ray tracing (circles)





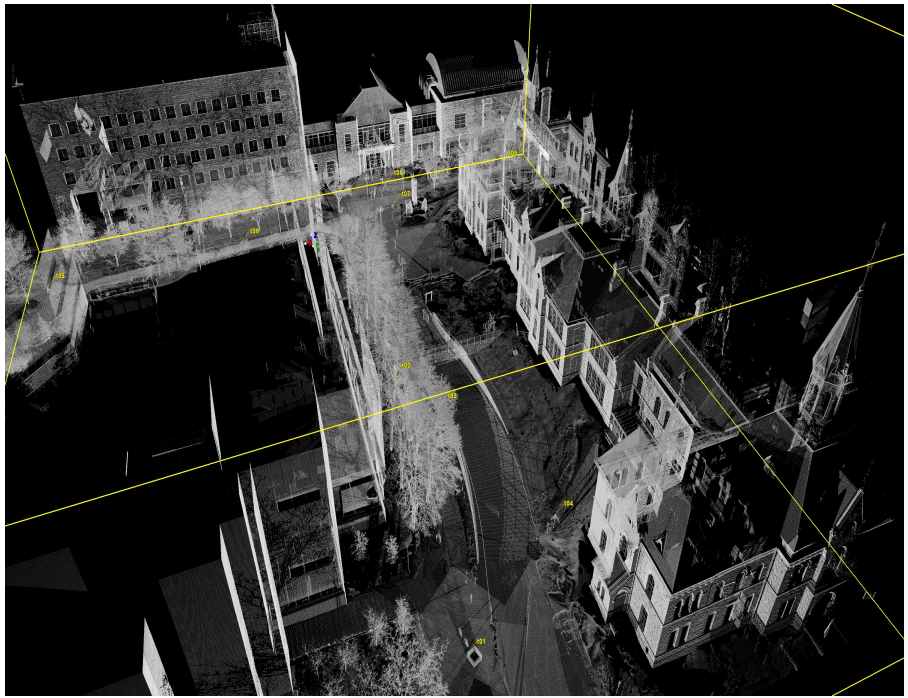
Modelling and Simulation Aided by Scanning

- Signals impacted by local environment
- Non line-of-sight regions known to impair communications
- Validated simulations may enable pre-planning for coverage by 5G base stations

Outdoor Experimental Location-
Ottawa City Hall District

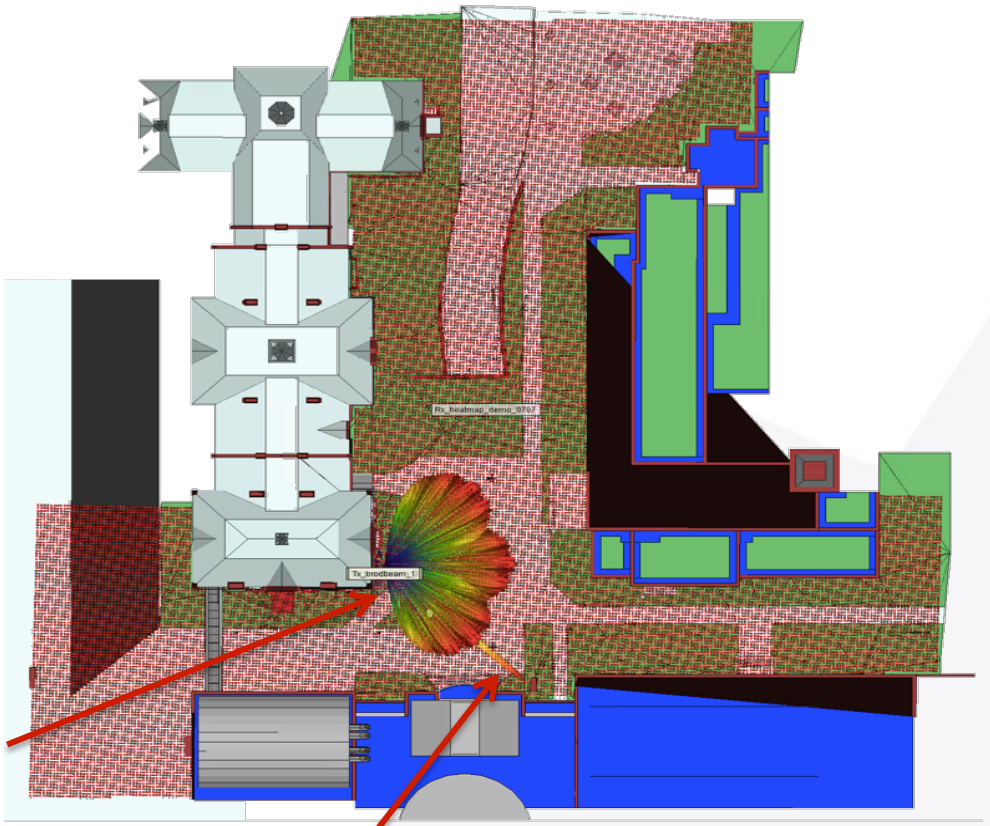
LIDAR SCAN and Conversion into Ray Tracing Models

- Scanning aids in automation of modelling
- Leverage existing LIDAR scans of urban areas

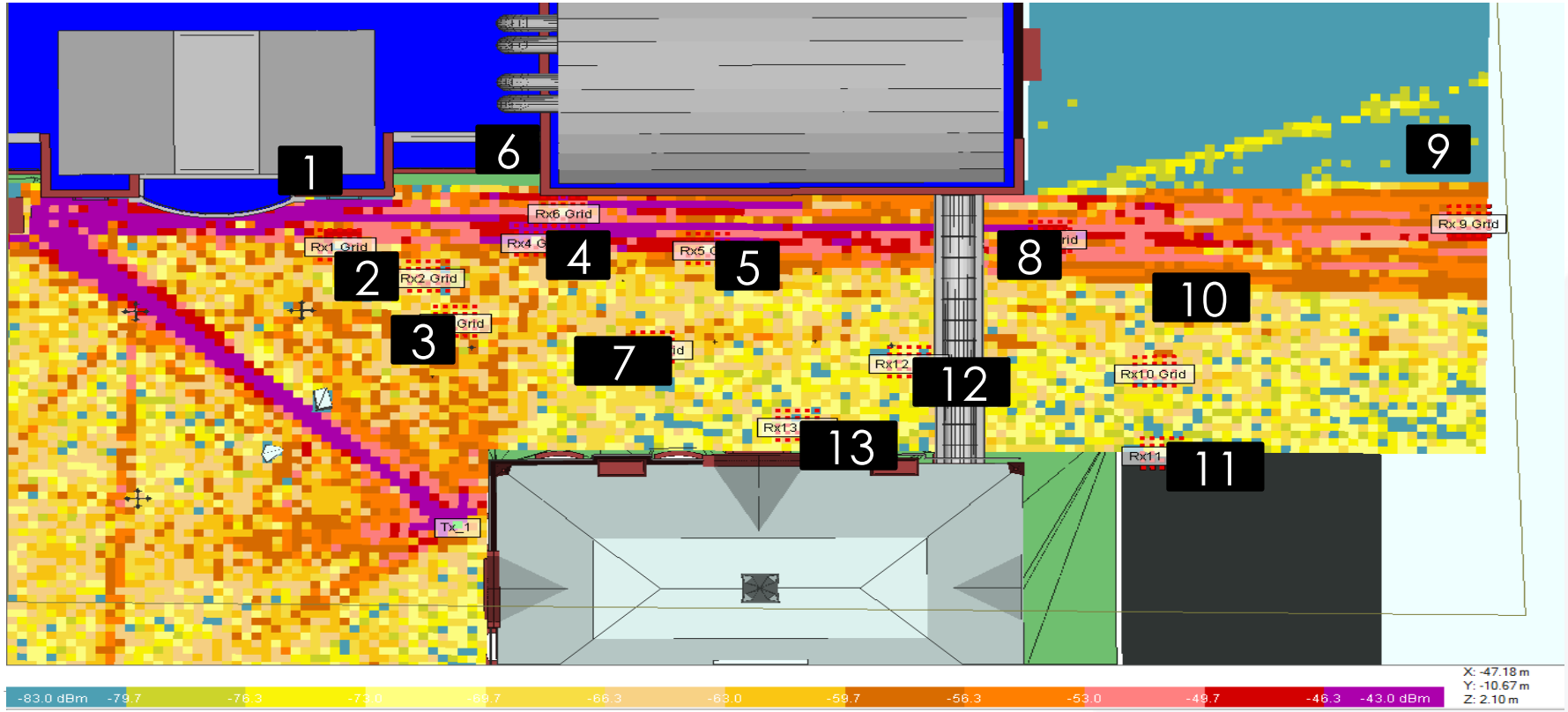


Ray Tracing simulation Parameters

- 16 dBm base station power
- Broad beam Tx, Gain=10dBi, narrowbeam Tx Gain 37 dBi
- Link operates -67.6dBm
- Number of Rx's is 29,281
- Run time/simulation ~10 hours
- Runs on virtual machine in cloud



Simulation and Measurement Received Power Comparison



Received Power- Measurement and Simulation

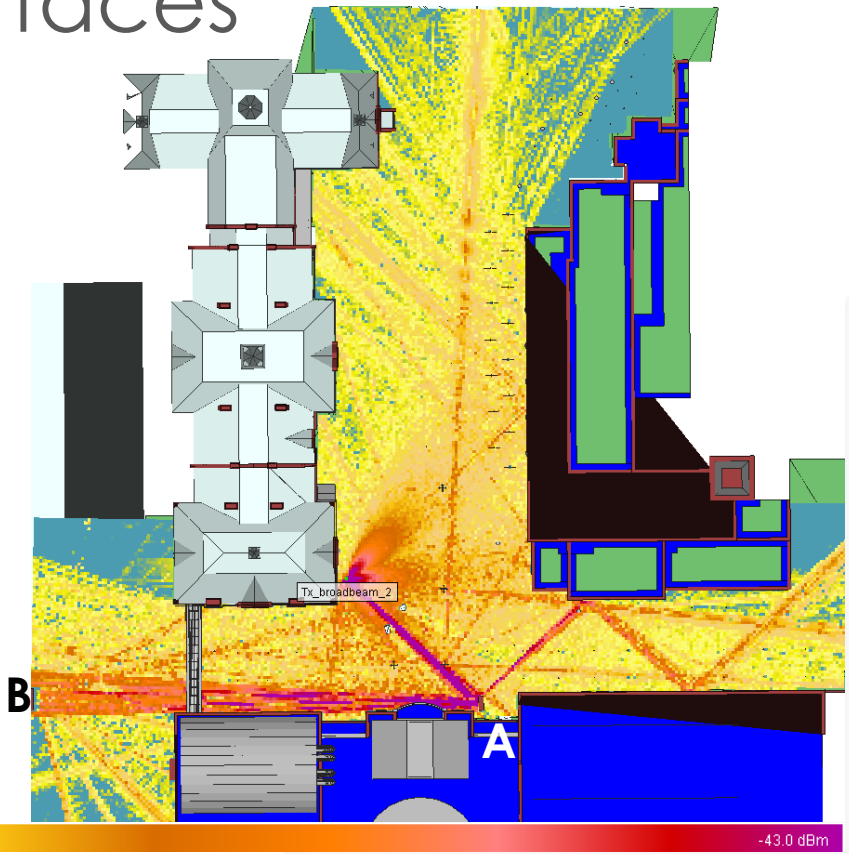
Variation

- Single measurements at each location
- Simulation used 25 Locations on a 2m x 2m grid centred on measurement
- Variation at these 25 points may be due to fading
- Imperfections due to differences in real/modelled antenna patterns while identical gains
- **Majority of cases show measurements within simulation range**

Rx#	Simul Max (dBm)	Simul Min (dBm)	Meas. (dBm)
1	-60.5	-80.5	-64.3
2	-60.7	-77.2	-63.9
3	-57.2	-76.6	-67.6
4	-62.0	-75.5	-72.3
5	-73.3	-97.6	-74.9
6	-61.9	-91.0	-69.6
7	-54.8	-92.4	-69.3
8	-76.5	-99.2	-75.1
9	-82.3	-101.7	-85.0
10	-71.2	-100.5	-85.2
11	-66.7	-84.8	-75.8
12	-64.0	-102.5	-82.5
13	-64.7	-100.1	-85.7

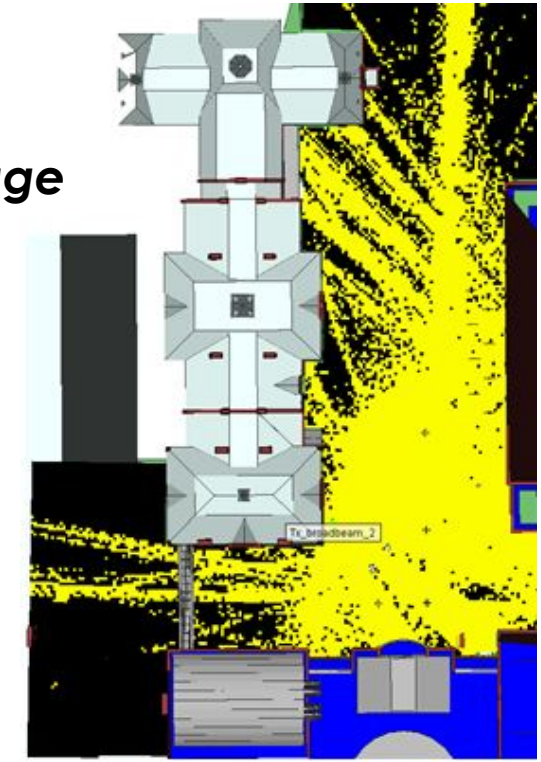
Coverage Enhancement using Static Engineered Surfaces

- Coverage can be extended by placement of reflectors at A and B



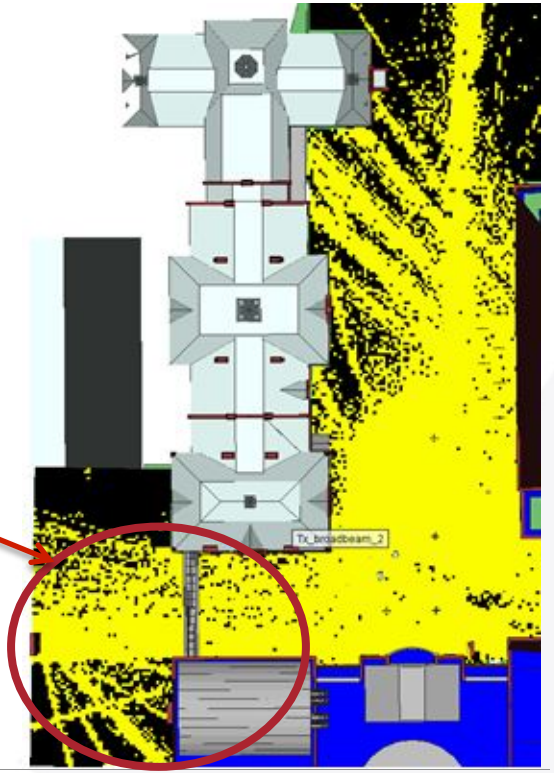
Impact of Engineered Surface Reflectors on Coverage with LTE at 28 GHz

Basic Coverage



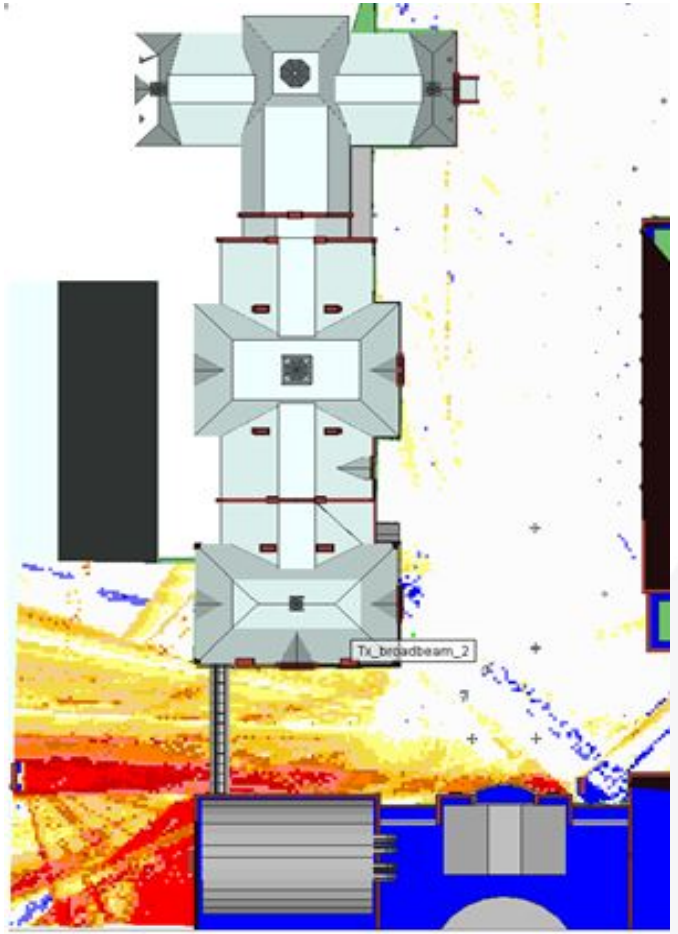
Enhancement from Reflectors

Improvement by careful placement of reflectors



Extent of Improvement

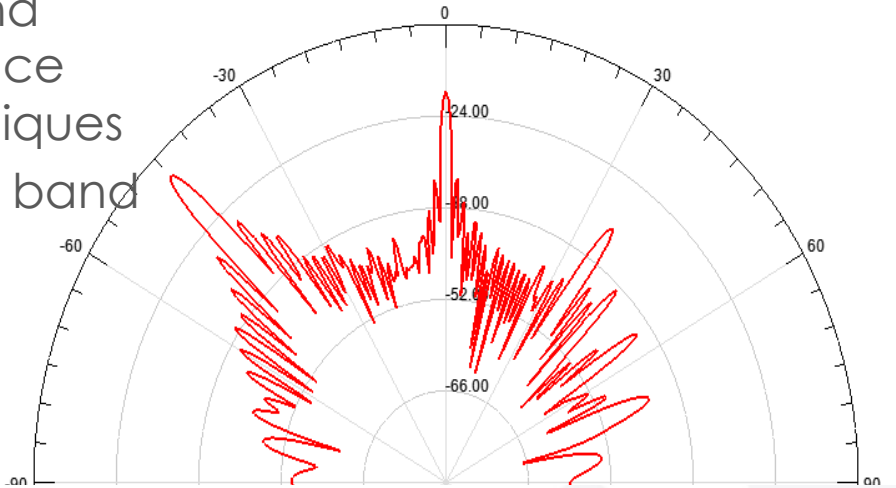
- Coverage is part of the story
- Power enhancement in extended area drives capacity
- A smart BTS that pushes energy onto reflectors can "harvest" that energy is regions otherwise lacking coverage

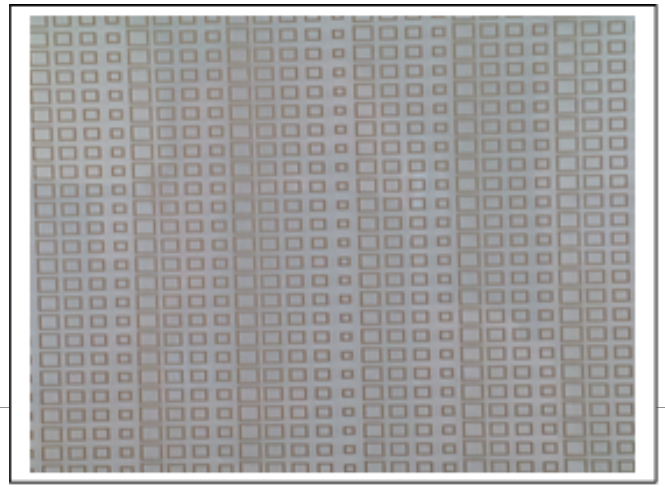


Difference in Rx power due to reflectors

Engineered Properties of Reflectors to Enhance Coverage

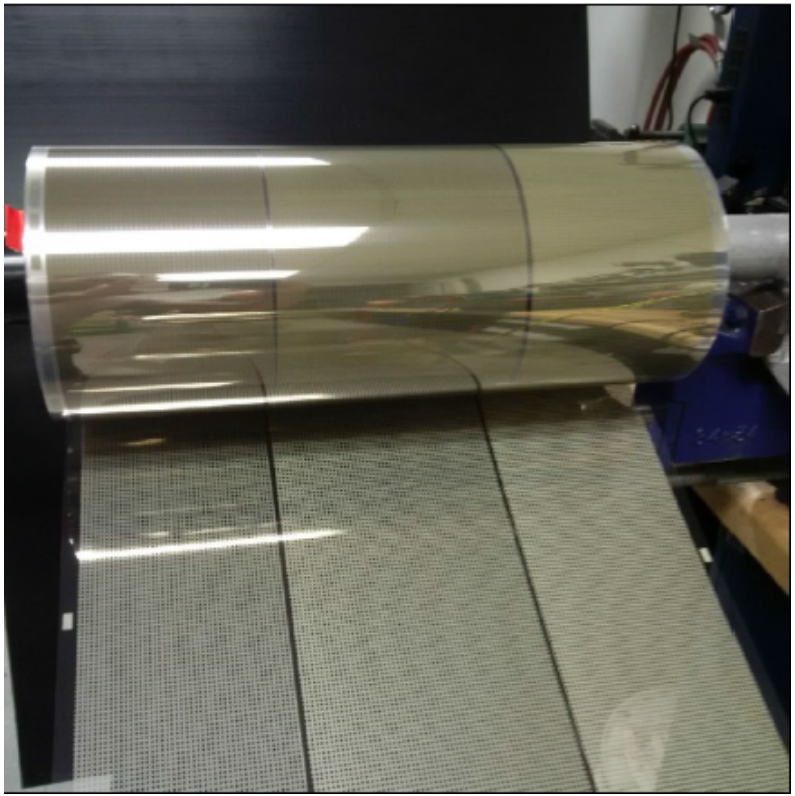
- Millimetre-wave signals redirected and spread over angular region to enhance coverage using spatial filtering techniques
- Frequency selective- impacts 28 GHz band only (or other desired)



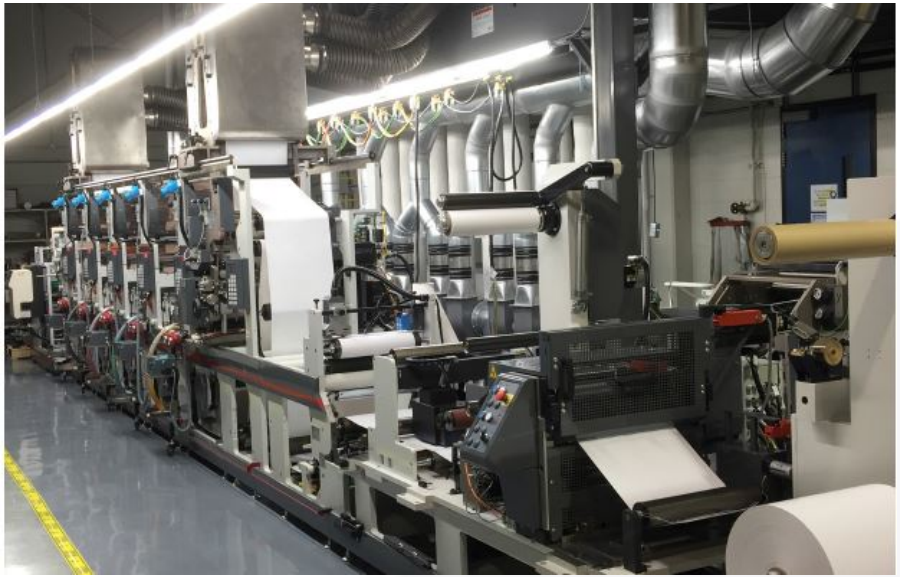


(Left) Grating for 28 GHz printed on 10 mil PET with 45 degree reflect as compared with incident (Above) RADAR cross section for normal incident and 45 degree reflection at 28 GHz

Engineered Surfaces via Printable Electronics



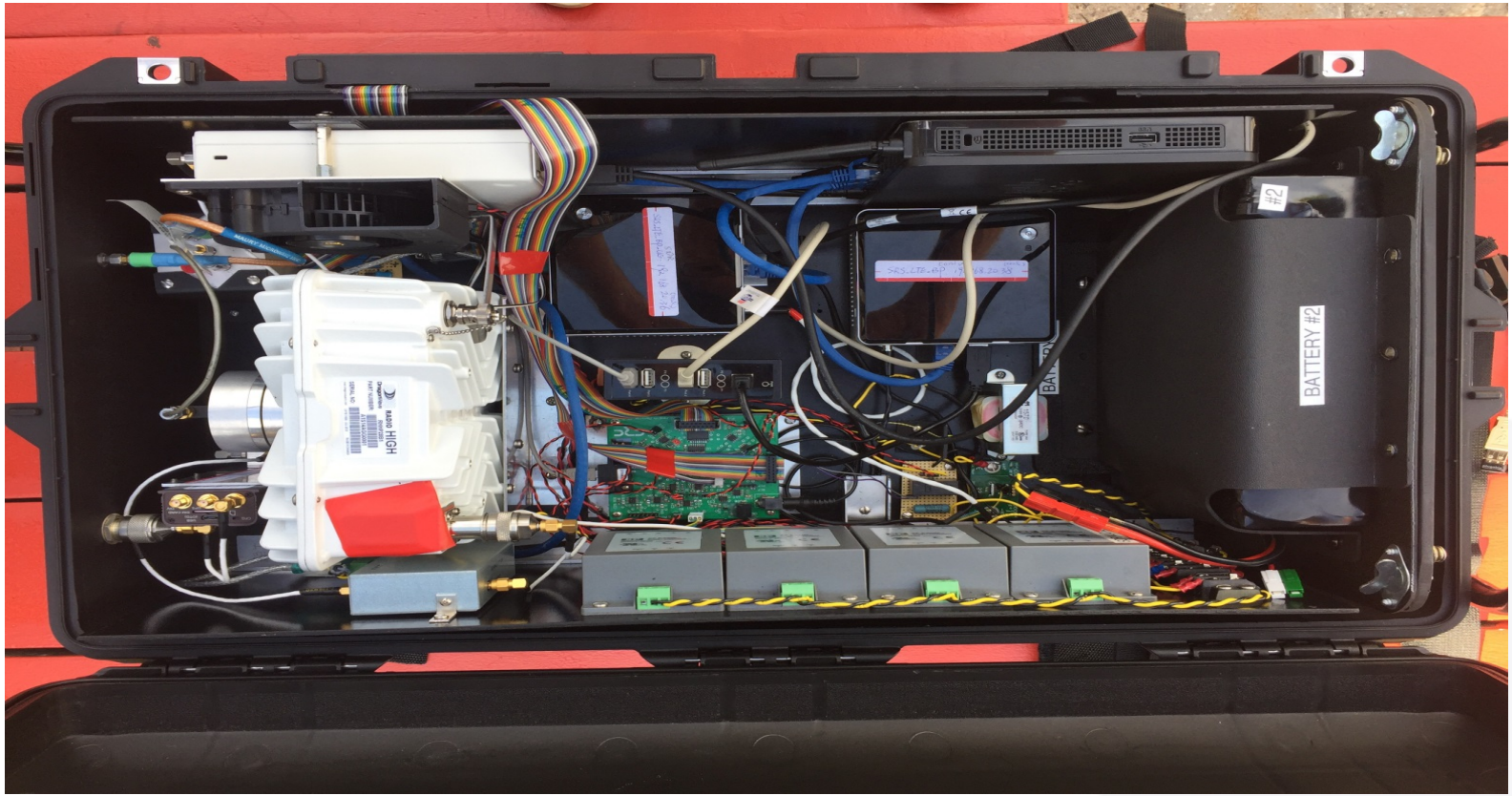
- Large scale printing on low cost PET plastic
- Use ink with conductive properties



Experimentation

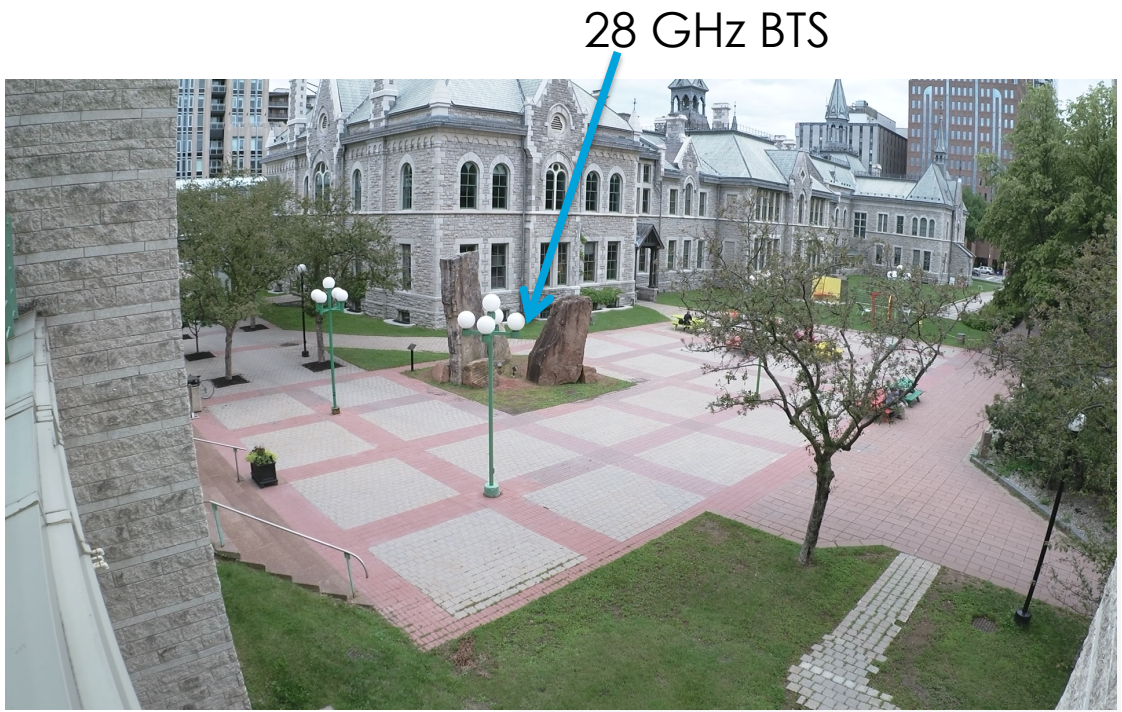
28 GHz UE

Interior of 28 GHz Backpack UE



5G Experimentation Testbed- Ottawa City Hall

- Experiment with 28GHz UE and BTS
- Outdoor testbed with primarily pedestrian traffic
- Partnership with City supports logistics and technical needs
- Spectrum sensors installed for realtime monitoring



Outdoor Experimentation Underway at Ottawa City Hall 2017

- Testing to validate simulation and performance prediction
- Validate engineering tools to automate deployment and engineer environment

Summary

- Work at CRC guided by desire to show what is possible and what works experimentally
- Methods to validate models and simulations have been devised and shown to work
- Designing for coverage using planning tools can reduce expertise-heavy site engineering


Canada

References for Engineered Surface Designs

- M. R. Chaharmir and J. Ethier, "Design of a dual-band 13/24 GHz frequency selective surface using meandered loop elements," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, Montreal, QC, 2016.

- M. R. Chaharmir, J. Ethier, D. Lee and J. Shaker, "Design of dual-band frequency selective surfaces to block Wi-Fi using printable electronics technology," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, Montreal, QC, 2016.